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Preliminary Assessment of Qiskit Quantum Simulator Capabilities for Development of Quantum Hopfield Neural Network for Anomaly Detection Applications

Consortium on Nuclear Security Technologies (CONNECT) Q4 Report

Nuclear Science and Engineering Division

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prepared by
Luis Valdez[1,2], Alexander Heifetz[1]

[1]Nuclear Science Engineering Division, Argonne National Laboratory
[2]Department of Electrical and Computer Engineering, University of Texas at San Antonio

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Abstract

Quantum information processing offers potentially faster performance compared to the classical counterpart. The goal of this work is to investigate performance of Quantum Hopfield Neural Network for applications to anomaly detection. Preliminary study consist of assessment of computational capabilities of Qiskit quantum simulator. Eventual objective is to implement Quantum Hopfield Network algorithm for detection of weak nuisance and anomaly signal in the presence of strong and highly varying background in gamma radiation data measured during environmental screening.

1. Introduction

Environmental screening of gamma radiation consists of detecting weak nuisance and anomaly signal in the presence of strong and highly varying background. In a typical scenario, a mobile detector-spectrometer continuously measures gamma radiation spectra in short, e.g., one-second, signal acquisition intervals. Detecting sources from data measured in a search scenario is difficult due to the highly varying background because of naturally occurring radioactive material (NORM), and low signal-to-noise ratio (S/N) of spectral signal measured during one-second acquisition intervals [1-3]. In prior work, we developd a Hopfield Artificial Neural Networks (HANN) to detect a weak signal anomaly hidden among the highly fluctuating background spectra [4]. In this report, we explore development of Quantum Hopfield Neural Network for applications to anomaly detection.

Quantum computing is an emerging subject on the interface of computing engineering and quantum engineering, which applies quantum theory to develop faster and accurate computational system, as compared to classical computer performance. Quantum computer architecture is based on qubits (quantum bits) and logic gates. Quantum computer focuses in three main properties to accomplish computation: Superposition, Entanglement and Interference. While quantum computer hardware is still under development, there exist quantum-computing simulators, which allow for development and testing of quantum algorithms performance on a classical computer. One the most popular packages with estimated 300,000 users is IBM quantum simulator Qiskit, which is an open source Python software. In this report, we describe circuit simulator and algorithm simulator, which are the two of the main tools in Qiskit [5].

2. Qiskit Quantum Circuit Simulator

Quantum circuit is an interactive library provided by Qiskit to represent, qubits, logic gates, quantum functionalities and quantum states. Quantum bit or qubit is a unit of information processing on a quantum computer, similar to a bit of a classical computers. The benefit of qubits is that we can represent them as *n*-dimensional states in Hilbert space, giving us the advantage of quantum parallelism. In a classical computer, bit states are 0 or 1. Qubits are represented by |0> and |1> in vector space representation (Dirac notation Bra and Ket vectors). Figure 1 displays qubit representation graphics of Qiskit visualization.

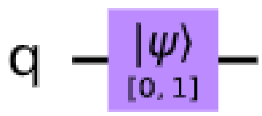

Figure 1 – Qubit visualization in Qiskit

Figure 2 shows qubit vector representation. Figure 3 visualizes qubit measurements in Qiskit quantum circuit.

$$|0\rangle = \begin{bmatrix} 1 \\ 0 \end{bmatrix} \quad |1\rangle = \begin{bmatrix} 0 \\ 1 \end{bmatrix}.$$

Figure 2 – Qubit states

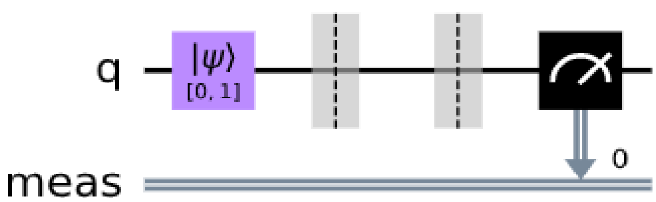

Figure 3 – Qubit measurement in Qiskit

Just as their classical counterpart bits, qubits can be added and subtracted or combined in different logic gates. The most useful gates to process qubits are NOT (X) and CNOT (CX) and Hadamard (H) gates in Qiskit library. The X gate shown in Figure 4 switches the value of the qubit to the opposite value (0 to 1 and 1 to 0). The CX gate shown in Figure 5 acts as an equivalent of a classical adder on a quantum computer. Figure 6 shows a diagram of a circuit consisting of X and CX gates.

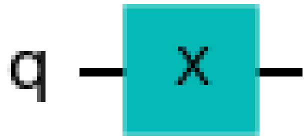

Figure 4 – Qiskit X gate

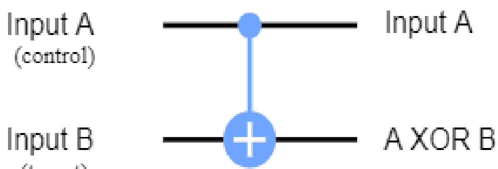

Figure 5 – Qiskit CX gate

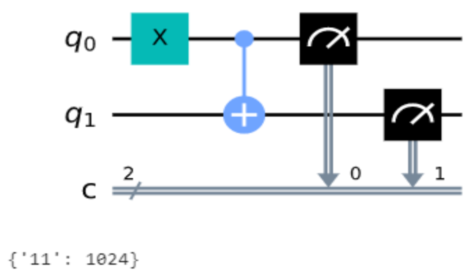

Figure 6 – Qiskit circuit consisting of X and CX gates

The H gate in Qiskit, shown in Figure 7, allows to create a qubit in a superposition of two states.

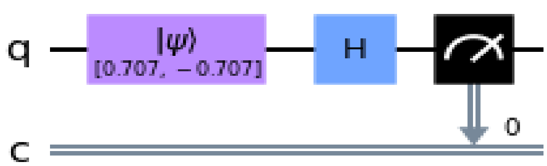

Figure 7 – Qiskit H gate

Entanglement is the most important feature of a quantum computer. If two qubits are entangled, measurement of the state of on qubit automatically determines the state of the other qubit. Entanglement can be created in Qiskit circuit by combining H and CX gates, as shown in Figure 8.

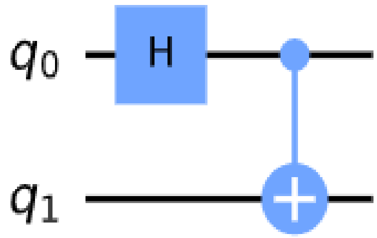

Figure 8 – Entanglement of qubits in Qiskit

3. Qiskit Algorithm Libraries

Qiskit is developed with Python application programming interface (API), and compatible with Python development environment, such as Anaconda. Quantum algorithm libraries have several API interferences that support Engineering Analyses and machine learning interfaces. Qiskit libraries we can be invoked using Jupiter notebook under Anaconda platform. Several examples shown in Figures 9 through 13 demonstrate samples of code utilized to run qubits, gates and to simulate entanglement using Qiskit Python libraries. Figure 9 shows an example of importing libraries from Qiskit. Figure 10 shows an example of initializing and creating a quantum state. In Figure 10, a call is made to Qiski to the simulator to display the resulting states. Figure 11 shows the call to Qiskit to simulated quantum circuit. Figure 12 shows code snippets to issue command to run the results and display qubit quantum states. In Figure 13, a call is made to print qubit states.

```python
from qiskit import QuantumCircuit, assemble, Aer
from qiskit.visualization import plot_histogram, plot_bloch_vector
from math import sqrt, pi
```

Figure 9 – Import libraries

```python
qc = QuantumCircuit(1)  # Create a quantum circuit with one qubit
initial_state = [0,1]   # Define initial_state as |1>
qc.initialize(initial_state, 0) # Apply initialisation operation to the 0th qubit
qc.draw()  # Let's view our circuit
```

run restart

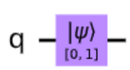

Figure 10 – Initialize state and create a quantum circuit (optional for visual representation)

```python
sim = Aer.get_backend('aer_simulator')  # Tell Qiskit how to simulate our circuit
```

run restart

Figure 11 – Call Qiskit to simulate quantum circuit

```
qc = QuantumCircuit(1)  # Create a quantum circuit with one qubit
initial_state = [0,1]   # Define initial_state as |1>
qc.initialize(initial_state, 0) # Apply initialisation operation to the 0th qubit
qc.save_statevector()   # Tell simulator to save statevector
qobj = assemble(qc)     # Create a Qobj from the circuit for the simulator to run
result = sim.run(qobj).result() # Do the simulation and return the result
```

run restart

Figure 12 – Run the result to display qubit states

```
out_state = result.get_statevector()
print(out_state) # Display the output state vector
```

run restart

```
[0.+0.j 1.+0.j]
```

Figure 13 – Print qubit states

4. Conclusions

Qiskit allows to simulate quantum operations, such as entanglement, using visual quantum circuit simulator tools. Interfacing with Python libraries allows to run Qiskit quantum algorithms for a variety of applications. Future work will focus on implementation of Quantum Hopfield Neural Network algorithm in Qiskit.

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Nuclear Science and Engineering (NSE) Division
Argonne National Laboratory
9700 South Cass Avenue, Bldg. 208
Argonne, IL 60439

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